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# Resource recycling and waste-to-energy: The cornerstones of circular economy

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***ABSTRACT:*** *"Circular Economy" is the pursued goal of sustainable development of mankind for the 21st century. In short, the fundamental spirit of circular economy is the concept of "Zero Waste". The example used in our daily lives means 100% of waste treatment, leaving no trace. At this time, it would be an ideal goal that the waste could be fully recovered into available raw materials or energies. In particular, "waste-to-energy" is a key factor, because all the wastes are almost related to energy. Resource recycling of waste metal from the household garbage is the best example. When smelting metals, the refining industry needs to reduce the metal oxides (mineral materials) to metals, such as steel, aluminium, copper, etc. The reduction processes consume considerable portion of energy for the entire smelting process, for example, 70.6% for steel and 77.4% for aluminium. However, if the waste metallic products can be fully recovered, as long as by melting and reshaping, the original oxide metal reduction processes that consume a lot of energy can be avoided. On the other hand, when the general garbage cannot be recovered as a resource, they can be converted into fuel or electricity by biological or thermal treatment. Another more important human waste utilization is the waste paper recycling. The production of one tonne of raw pulp emits about 6 tonnes of carbon, consuming about 100 cubic meters of water, using about 200 kilograms of chemical raw materials, and draining 300 tonnes of toxic waste water. The entire papermaking process is how terrible environmental pollution! The recycled pulp of one tonne can save energy 10-13GJ.The proportion of paper waste in Taiwan 2015 is 34.69% and the estimated amount is 2.5 million tonnes. If the paper waste could be fully recycled, it could save energy about 0.725 million kloe (kilo-litre oil equivalent). In other words, it virtually reduces Taiwan's oil imports of 4.56 million barrels and* $CO_2$ *emissions of 2.5 million tonnes annually.*

***KEYWORDS:*** *Waste-to-energy; Recirculation; Recycle; Garbage; Taiwan.*

## I. INTRODUCTION

The term "circular economy" was first proposed by American economist Kenneth E. Boulding in the 1960s, arguing that the spacecraft is an isolated, independent system that relies on the constant consumption of its own resources and it will be destroyed due to the depletion of resources. The only way to extend life is to achieve the resources circulation within the spacecraft, as far as possible to reduce the discharge of waste. Similarly, the Earth's economic system is like a spacecraft, although the Earth's resources system is much larger and the Earth's life is much longer, the Earth can survive only through the concept of the circular economy by the implement of resources recycling. In fact, there had been an equivalent saying of circular economy in ancient China, namely, the so-called “people do their best, make the most advantage of land, make the best use of articles, and make the smoothest flow of goods”. The two concepts from America and China basically have the same spirit. Therefore, the principle of zero waste of circular economy can be applied to any resources, including articles, land, materials, and people ourselves. Waste generated by humanity according to the physical shape can be divided into three types: liquid, solid and gaseous. General waste based on the use sources or garbage producers can be sorted into following categories: agriculture, forestry, animal husbandry, general living, and industry. According to above types and sources, the current waste-to-energy items can be detailed as the following.

(A) Agricultural, forestry, and animal husbandry wastes, including: forest harvesting and tending residues, wood processing residues, crop stalks, agro-processing residues and livestock and poultry breeding excrement. In terms of pattern, the agriculture and forestry wastes include a wide variety of wastes, such as straw, trees, leaves and others (Ko et al., 2014). If agricultural and forestry wastes are treated by "residue derived fuel (RDF)" technology, the waste processed into solid-state ingot-type fuels for direct combustion or co-firing with other

fuels will be through the procedures of crushing, sorting, drying, additives mixing, and forming (Karellas et al., 2010). Livestock and poultry excretions can produce biogas and burn as fuel and/or for power generation.

(B) Industrial waste, including: industrial organic and inorganic waste and high concentrations of organic wastewater.

(C) Municipal solid waste: the common items are paper, kitchen residue, metal, plastic, rubber, paper, etc (Guerrero et al., 2013). The nature of waste can be divided into organic and inorganic wastes, the former such as kitchen residue, which generally can be buried to produce biogas, whilst the biogas can burn to generate power and avoid greenhouse gas emissions; additionally, the combustible part of the inorganic waste can be incinerated, while its waste heat can be utilized for power generation; meanwhile the non-flammable metallic part can be recycled as resources and recovered into metal raw materials.

## II. TAIWAN'S WASTE-TO-ENERGY POTENTIAL, THE STATUS QUO, AND THE FUTURE

As shown in Table 1, Taiwan's waste-to-energy potential can be estimated partially from the amount of municipal, agricultural, and forestry wastes. The total recyclable energy of these wastes is 30,641.75GWh/year, equivalent to the power generation of 12,260.92GWh annually with a conversion efficiency of 40% (Chen et al., 2010; Lu, 2016). Among these resources, the agroforestry waste has the highest calorific value, but the cost is relatively low. The agro forestry waste is quite different from the biomass crop that needs a large area of arable land. However, from the economic point of view, the most important prerequisite is that the high-performance power plants should be installed near the waste collection site to facilitate the access to waste resources produced from the industry, agriculture, forestry, city, and so on. Biomass is widely used in Taiwan, including biogas from livestock and poultry excrements as well as the household, industrial and agricultural wastes. Wherein, the wastes are processed through the procedures of burial, gasification, decomposing, and fermentation in order to produce biogas. As the biomass energy has the dual contributions of energy supply and environmental protection, so biomass energy is the most popular renewable energy in the world, accounting for the two-third of the total RE application globally (Iakovou et al., 2010). Taiwan's biomass energy reserve is about 3Mtoe, accounting for 40% of the total potential for renewable energy development in the country.

**Table 1 Taiwan's waste power generation potential assessment**

| | **Power generation capacity(GW)** | **Power generation(GWh/year)** |
|---|---|---|
| **Municipal waste** | 1.07 | 1,208.88 |
| **Agriculture and forestry waste** | 3.15 | 1,1047.82 |
| **Total potential** | **4.22** | **12,260.92** |

Data source: Chen et al., 2010; Lu, 2016.

On a larger scale, the total biomass energy reserve and equivalent annual electricity generation in Taiwan are 5.08GW and 15,278.90GWh respectively (Lu, 2016). As shown in Fig.1 and Table 1, Taiwan's waste-to-energy mainly comes from landfill gas and waste incineration (Lu et al., 2006). These two types of energy production constitute the main supply of renewable energy in the country. By the end of 2015, there are more than 70 installation sites, with a power generation capacity of 629.1MW, which generates 3,243.7GWh of electricity annually (Lu, 2016).

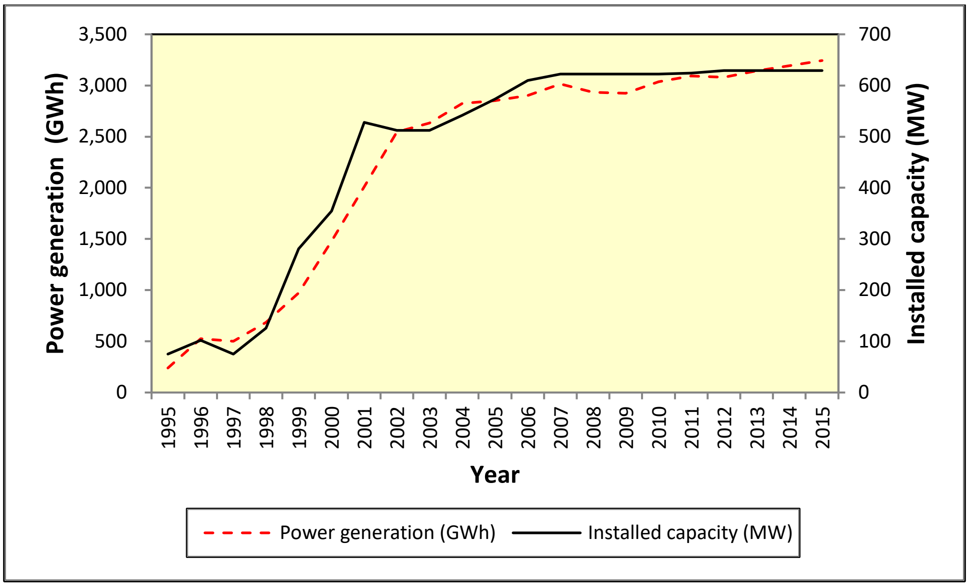


**Fig.1 Taiwan's waste power generation and installed capacity** (1995-2015) Data sources: BOEMOEA Energy Statistics Handbook for 2015; Lu (2016); Tsai (2016).

Since 1999, the Industrial Technology Research Institute (ITRI) has implemented the "Waste-to-Energy Utilization Technology Development and Extension Program", wherein the RD & D priorities are the development and application of waste-to-energy technologies such as landfill gas, gasification, liquefaction, and refuse derived fuel (RDF). Table 2 shows Taiwan's waste-to-energy status, objectives, and promotion strategies that were announced by the Bureau of Energy Ministry of Economic Affairs (BOEMOEA) in 2016.

Table 2 Taiwan's waste-to-energy development status, objectives, and strategies

| 2015 Status (Percentage) | Goal | Goal-driven strategy |
|---|---|---|
| 629.1 MW (1.29%) | • 925 MW (2020)<br>• 1,369 MW (2030) | •Municipal waste (622.5MW): utilize waste heat of incineration to generate electricity.<br>•Agricultural and industrial waste (167.5MW): on the base of power generation and thermal applications.<br>•Biogas thermoelectric applications (8.5MW): on the base of landfill biogas power generation. |

Sources: Lu, 2016.

As shown in Table 3, the total amount of agricultural, livestock and poultry wastes in Taiwan is as high as about 27.2 million tonnes, according to the data released by the Bureau of Energy of the Ministry of Economic Affairs in 2015, of which the excreta of pigs and poultry accounts for the majority. On the base that one kilogram of pig and chicken excrement produces 60 litres and 70 litres of biogas respectively, it can be estimated that there is a total of about 1,834 million cubic meters of biogas reserved in Taiwan. Recently, the Taiwanese government intends to promote power generation from burning the biogas produced from the livestock and poultry wastes. In addition to that it can create additional energy for the country, at the same time it can solve the environmental and health problems for the people. In the case of Kaohsiung's Shih-An Farm, the introduction of Danish CSRT livestock and poultry biogas power plant, which can handle 80 tonnes of chicken manure per day, through the fermentation process, produces biogas of 8,000 m3 daily, thereby generating electricity more than 5GWh per year. Accordingly, the Taiwanese livestock and poultry excrement have the potential to generate electricity of 1,700TWh per year.

Table 3 Agricultural, livestock and poultry wastes statistics (2014)

| | **Total production** | **Waste per unit** | **Total amount of waste** | **Producible biogas** |
|---|---|---|---|---|
| **Rice** | 1,600 tonnes | 86 kg/tonne | 137.6 tonnes | - |
| **Sugar** | 500 tonnes | 250 kg/tonne | 125 tonnes | - |
| **Pig** | 8 million tonnes | 2.4 kg/head/day | 7 million tonnes | 420 x $10^9$ litre |
| **Poultry** | 370 million tonnes | 0.15kg/head/day | 20.2 million tonnes | 1,414 x $10^9$ litre |
| **Subtotal** | ~380.1 million tonnes | - | ~27.2 million tonnes | 1,834 x $10^9$ litre (~power generation 6,113.38TWh) |

Note: burning 1m3of natural gas can get 0.04GJ of heat, while with 30% of thermal conversion efficiency, 3.33 kWh of electricity can be generated. Source: BOEMOEA (2015); https: //energypedia.info/wiki/Electricity_Generation_from_Biogas

At the same time, RDF technology has been gradually developed maturely in Taiwan. A solid RDF made of waste has the following advantages: high calorific value, uniform and stable material properties, combustion easy to control, low pollution, easy transport and storage, as a fuel for boiler and cogeneration, with low environmental impact and high energy recovery efficiency and so on. At present, the RDF technology has been transferred from the ITRI to the industry (Wei and Huang, 2001).A demonstration RDF production plant has been set up in the Hyaline city to process the garbage and other wastes into useful fuels. In addition, due to the successful development of liquefaction and gasification technology, it is possible to convert the waste into useful fuels for boiler and turbine, including the composite fuels or syngas: $H_2$, CO, $CH_4$, etc., which are burned to produce steam and electricity, thus that the environmental protection, waste self-management, clean production, and other objectives are achieved.

At present, the ITRI has successfully developed specific practical technologies to produce energy from solid waste, such as rice hull gasification and waste polystyrene liquefaction. These technologies have been successfully transferred to the industry through patent licensing. In the 1960s, Taiwanese economy boomed notably in such way that a remarkable miracle is created nowadays. Since Government focused on the economic development, the environmental protection was ignored, such as the garbage disposal rate is not high and so on, resulting in several serious threats and impacts on the environment. In the evolution of waste disposal policy, the “burial” was focused in the early days, then switching to the "incineration-based and burial as a supplement" manner in the later times. At that time, a large number of incinerators were built around Taiwan in order to handle the increasing general wastes generated by the growing population.

In recent years, Taiwanese environmental protection policy is adjusted; namely, "waste reduction and resource recovery” become the priority. Not only per CapitaLand daily garbage is reduced, but the total amount of waste is also decreased year by year, all for the purposes to promote the development of green industry and to create a circular economy. Essentially, the incineration itself is an energy use technology. Since the construction of incineration plants in Taiwan, the waste is thermally treated for power generation. However, foreign technology has been gradually adjusted and advanced. In the expectation of improving energy efficiency, raising the heat conversion rate becomes the main point, in which the gasification technology and the cracking technology should be worth noting in the future. In fact, the gasification technology has two major advantages. First, the energy efficiency is relatively high, which may increase to 30% to 35%from the current incineration of the average energy efficiency of about 20% to 25%.Secondly, due to the operating environment of less oxygen demand, emission of pollutants is relatively small. Therefore, as the combination of the above factors, the gasification technology has many merits, such as for energy use, good combustion efficiency, less pollutant, and fewer emissions. We can see in future that gasification can be regarded as an alternative waste disposal technology for current incineration technology (EPA, 2016b).

## III. ENERGY AND ENVIRONMENTAL BENEFITS OF TAIWAN'S RESOURCES RECYCLING

In Taiwan, the industrial sector has the highest final energy consumption among the all energy consumption sectors, in the past decade, accounting for 45-54% in the national energy consumption and for 40-45% in the economic scale of GDP.

**Metallic waste recycling: taking steel and aluminium as an example :** Clay-like bauxite, an important source of aluminium, contains 50-60% of A12O3.The purity of bauxite is improved through special mechanical processing, then by means of chemical treatment to precipitate alumina, followed by melting alumina into cryolite and electrolytes, under the electrolysis process, separating aluminium from liquid, finally the aluminium liquid poured into mould to form ingot, thus the alumina formally smelted to an electrolytic aluminium or primary aluminium. The purity of standard aluminium registered in London Metal Exchange (LME) is 99.7% of the electrolytic aluminium. The electrolytic aluminium production process is formulated as follows:

4 to 5 tonnes of bauxite (Bayer method) → 2 tonnes of alumina (Hall-Heroult electrolysis) → 1 tonne of electrolytic aluminium (1)

The Hall-Heroult process is an electrochemical process: when at 940-960℃, 60-350KA DC through the carbon anode, the alumina, in a molten state, contained in an electrolytic cell in the molten fluoride, is reduced into aluminium and carbon dioxide. The whole electrolytic aluminium chemical reaction is as follows:

$$2\ A1_2O_3 + 3C = 4Al + 3CO_2 \qquad (2)$$

The manufacture of one tonne of alumina requires about 2-2.5 tonnes of bauxite and consumes 8,500-12,000MJ of heat, while the manufacture of one tonne of aluminium also requires two tonnes of alumina. In 1950, the production of 1 tonne of raw aluminium consumes 20,000kWh of electricity, which has dropped below 13,000kWh currently, whilst 11 tonnes of $CO_2$ is produced simultaneously. The aluminium industry still needs to consume large amounts of electricity, so the aluminium plant is located in the production site of bauxite and the areas with cheap electricity (Lu, 2014).

The most abundant four elements in the Earth's crust are oxygen, silicon, aluminium, and iron, so iron and aluminium are the two most commonly used metals in our daily lives. However, the iron and aluminium exist in nature in the form of oxides. During the refining processes, in which the metal oxides are reduced into pure metal, a considerable amount of energy is consumed and a lot of greenhouse gas (i.e., carbon dioxide) is emitted. As mentioned above, refining one tonne of steel requires 0.57 kloe of energy and emits 1.68 tonnes of carbon dioxide, whilst refining one tonne of aluminium needs 13,000kWh of electricity and emits 11 tonnes of carbon dioxide (Lu et al., 2013).

As shown in Fig. 2, the blast furnace (reduction process) consumes energy accounted for 70.6% for the all energy consumption in a consistently operational steelmaking plant. At the meantime, in the reduction process by smelting aluminium from bauxite (alumina), the energy consumption is accounted for 77.4%.So if the metallic scraps(e.g., wastes contains iron and aluminium) are recovered and then directly melted and moulded (Fig.2), the metallic oxides reduction processes that consume a large portion of energy can be skipped. In such manners of waste recirculation, the production of one tonne of steel can save 0.40 kloe of energy, reducing 1.19 tonnes of carbon dioxide emissions. With the same manner, the production of one tonne of aluminium can save the electricity of 10,062kWh and reduces 8.51 tonnes of carbon dioxide emissions (Lu, 2013).

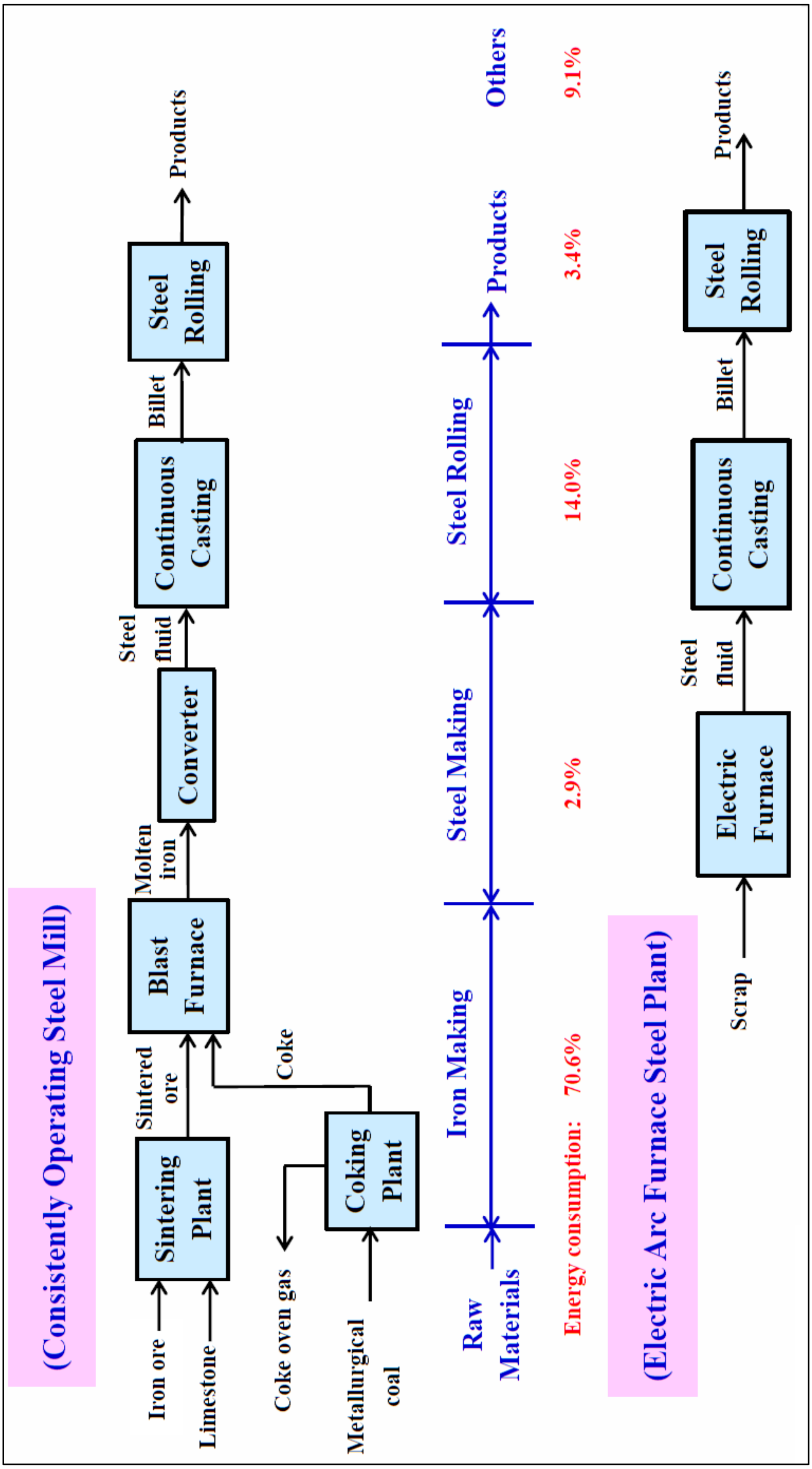
(Consistently Operating Steel Mill)
Iron ore
Limestone
Sintering Plant
Sintered ore
Blast Furnace
Molten iron
Converter
Steel fluid
Continuous Casting
Billet
Steel Rolling
Products
Coke oven gas
Metallurgical coal
Coking Plant
Coke
Raw Materials
Iron Making
Steel Making
Steel Rolling
Products
Others
Energy consumption: 70.6%
2.9%
14.0%
3.4%
9.1%
(Electric Arc Furnace Steel Plant)
Scrap
Electric Furnace
Steel fluid
Continuous Casting
Billet
Steel Rolling
Products

Fig. 2 Steel production processes According to the experimental results, it is found that the aluminium recovery is about 52kg for one tonne of beverage pack, and the purity is between 76~94%. For aluminium foil gasification, the aluminium recovery efficiency is between 76~91%. As a result, the aluminium recovery for one tonne of aluminium foil is 0.0354 tonnes (EPA, 2016b).

According to the resource recovery statistics analysed by the Environmental Protection Agency Executive Yuan for 2015, the recycling beverage packs made of aluminium foil is 44,170 tonnes, the aluminium cane is 56,926 tonnes, and the iron cane is 173,907 tonnes. On the base of the above data, Taiwan can fully recover and reuse 58,490 tonnes of aluminium and about 173,000 tonnes of iron for one year, thereby saving electricity of about 588.53GWh (146 million kloe) and energy of 69,200kloe respectively from the waste recirculation of aluminium and iron used products. In total, the metallic recirculation constitutes a total energy saving of 146.069 million kloe and GHG (greenhouse gas) emissions reduction of 703,620 tonnes of carbon dioxide, which are equivalent to the energy import of about 918 million barrels of oil and the construction of 1,809 Da'an Forest Parks.

Recycled pulp can save energy between 10-13 GJ/tonne, which is equivalent to the papermaking energy density of 0.29 kloe/tonne (Lu et al., 2013). According to the Annual Report on Environmental Protection in 2016, the proportion of paper waste in 2015'sTaiwan is 34.69% and the estimated amount is 2.5 million tonnes. If the waste paper can be fully recycled, it can save energy about 0.725 million kloe. In other words, this virtually reduces Taiwan's oil import by 4.56 million barrels. Black liquor is a by-product of the kraft or sulfate process in a pulp production course. Wherein, the wood is decomposed into cellulose fibres, hemicelluloses, and lignin fragments and the black liquor is a mixture of the lignin residues with hemicelluloses aqueous solutions as well as inorganic chemicals. The black liquor produced by the chemical pulping can be recycled as a boiler fuel to generate heat and electricity. In this case, one tonne of pulp can generate the combustion heat of about 22GJ (Kong et al., 2012). Due to the recycling of black liquor, a large-scale pulp mill can generate electricity for its own use or fed into the grid for sale. Meanwhile, one tonne of pulp produces about 10 tonnes of black liquor (Daya, 2012).

**Nuclear power plant waste**: Nuclear energy produces about 11% of the global electricity and is proposed as an alternative energy for petroleum fuels that are soon to be depleted. Up to now, 450 nuclear reactors around the world are actively operating in 31 countries. According to the environmental impact analysis, the total amount of waste generated by global nuclear power plants in the period of 40-50 years of power generation is about 200 cubic meters (Prelas et al., 2014). Because the radioactive wastes generated from a nuclear power plant are stored in a controlled manner, they do not pose a hazard to the environment. In addition, the nuclear waste storage technology is gradually evolving.

More importantly, nuclear energy plays a key role in the reduction of carbon dioxide emissions, which is a major GHG emission causing the global climate change, whilst the development of nuclear power can prevent other hazardous emissions as well, such as the sulfur dioxide, nitrogen oxides, and other gas or materials harmful to the human health. At the same power level, a nuclear power plant uses only one hundred thousandths of the fuel used in a thermal power plant but can provide the same amount of electric output. The used nuclear fuels, containing uranium (96%) and plutonium (1%), are valuable and useful resources that can be recycled through the reprocessing process and the final remaining waste is only about 3%. Theoretically, the volume and quantity of nuclear waste that is ultimately disposed or stored is very small. However, the used uranium still has radioactivity that lasts for thousands of years. 100% safe transport and storage of nuclear wastes are still unresolved in the world.

The closure of expired nuclear power plants is also a difficult and costly process. In the event of an accident, it has a great risk of radiative leakage and exposal. The most important and notable feature of the nuclear fusion plant is the absence of any radioactive elements. Nuclear fusion technology for power generation is currently being jointly researched and developed by the advanced industrialized countries and the commercial targets are expected to be achieved by 2050.

## IV. MUNICIPAL SOLID WASTE

In the latest decades, with the development of industrial and agricultural productions as well as the improvement of people's living standards, the solid waste displacement has been increasing notably. Right now, the waste annually generated in the world is about 45 billion tonnes under an astonished growth rate of 8-9% per year. In the western developed countries, the general increasing rate of waste is about 2-5% per year. In Japan, the per

capita annual average daily garbage dumping is nearly doubled in the last 10 years. In China, more than 6 billion tonnes of garbage has been accumulated over the years (Zhang et al., 2010).With a growth rate of 8-10% in each year, the large amount of garbage occupies 500,000 hectares of land, whereby more than 200 cities are buried in the sea of garbage (Bovea et al., 2010). The treatment of municipal wastes includes resource recovery, kitchen residue collection, incineration, sanitary burial, and others. The waste incineration can generate electricity, while the kitchen waste can be land filled to produce biogas that is burned for thermal energy use and power generation. In this case, one tonne of kitchen residue has a calorific value of 3GJ (Lu, 2012).

**Taiwan's garbage disposal situation** According to the Statistical Yearbook of Environmental Protection of the Republic of China in 2016, the average daily amount of waste generated in 2015's Taiwan is 0.844 kg per capita, wherein the kitchen residue accounts for 40.39%, the paper waste accounts for 34.69%, and the combustible components account for 97.94%. At present, the incineration ratio is 43.47%, the landfill ratio is 1.27%, and the kitchen residue recovery ratio is 8.43%.The total resource recovery ratio of Taiwanese garbage is45.92%. Compared with 2005, the amount of waste disposal is reduced by 7.66%, the waste incineration is decreased by 26.92%, and the amount of resource recovery is increased by 83.44%. In 2015, the amount of Taiwanese industrial waste is 19.16 million tonnes, in which 15.51 million tonnes is recycled under a utilization ratio of 82.51%. Taiwanese resource recovery is so effective and progressive that Taiwan has already become an example of success in the waste recirculation around the world (Table 4).

Table 4Data comparison with the relation to the electricity generation of municipal waste incineration in Taiwan

| | Garbage generation per person daily (kg) | Kitchen residue ratio (%) | Waste incineration ratio (%) | Large incinerator power generation (GWh) | Resource recovery ratio (%) |
|---|---|---|---|---|---|
| 2006 | 0.936 | 34.57 | 53.44 | 2,857 | 27.72 |
| 2007 | 0.951 | 32.86 | 54.54 | 2,960 | 29.97 |
| 2008 | 0.896 | 30.56 | 54.89 | 2,967 | 32.21 |
| 2009 | 0.920 | 37.42 | 52.11 | 2,925 | 35.32 |
| 2010 | 0.942 | 35.68 | 48.87 | 3,026 | 38.15 |
| 2011 | 0.892 | 39.21 | 45.91 | 3,076 | 40.40 |
| 2012 | 0.869 | 38.33 | 44.26 | 3,056 | 41.88 |
| 2013 | 0.861 | 35.07 | 43.76 | 3,131 | 43.00 |
| 2014 | 0.863 | 37.64 | 43.28 | 3,187 | 44.92 |
| 2015 | 0.844 | 40.39 | 43.47 | 3,217 | 45,92 |

Data sources: EPA (2016a)

**Solid waste:** Solid waste refers to the discharge of solid substances after the raw materials obtained from the resources are processed, product-produced, product-used or consumed, such as the garbage, the industrial waste, the agricultural waste, the hospital waste, etc. If exposed or simply land filled, the solid wastes not only occupy land, but also pollute the surrounding environment and the underground water. However, the solid waste is also a potential resource that can be achieved not only by renewable resources recycling but also in the way of energy use. The solid waste-to-energy utilization method is the best way to reduce the amount of solid waste, to avoid the environmental disaster, and to reuse the waste resource (Coroneos and Nanaki, 2012).

**Table 5 Composition characteristics of municipal waste in the major countries around the world.**

| Country | Composition (%) | | | | | | | Water Content (%) | Per capita annual displaceme nt(kg) | Calorific value (kJ/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ash | Food organic waste | Paper | Plastic | Metal | Glass | Others | | | |
| **UK** | 11 | 27 | 38 | 2.5 | 9 | 9 | 3.5 | 25 | 320 | 9,780 |
| **France** | 20 | 22 | 34 | 4 | 8 | 8 | 4 | 35 | 270 | 9,314 |
| **Netherlands** | 20 | 21 | 25 | 4 | 10 | 10 | 17 | 25 | 210 | 8,383 |
| **Germany** | 28 | 15 | 23 | 3 | 9 | 9 | 10 | 35 | 350 | 8,383 |
| **Switzerland** | 20 | 20 | 45 | 3 | 5 | 5 | 2 | 35 | 250 | 10,012 |
| **Italy** | 25 | 25 | 20 | 5 | 7 | 7 | 15 | 30 | 210 | 6,985 |
| **US** | 7 | 12 | 50 | 5 | 9 | 9 | 8 | 25 | 820 | 11,642 |
| **Taiwan** | 6 | 40 | 35 | 16 | 0 | 1 | 2 | 55 | 308 | 10,408* |

Note: *high calorific value (on wet base)

Data source: EPA, 2016a.

Domestic garbage usually includes paper, cloth, plastic, rubber, kitchen residue, vegetation, brick, sand, metal, glass, etc. However, the content of each component varies according to the regional living habits, economic development, and climate. In the developed countries, the production of municipal solid waste (MSW) is large, in which food waste, paper, cloth, plastic and other organic matter account for the major proportion. Meanwhile, the fuel content and calorific value in the MSW are also high. Refer Table 5 for the details of municipal waste composition in the major countries around the world. In Taiwan, over the past few years, the population of the city increases abruptly. Coupled with the improvement of living standards and the use of natural gas, the organic ingredients in the garbage gradually increase. Although the weight per capita waste reduces, the average calorific value increases.

**Hazards of Garbage:**
The hazards of garbage are summarized as follows.

(1) Pollution of water: with the eutrophication of high nitrogen and high phosphorus materials, the brown/black infiltration liquid accumulated in the garbage field is the garbage liquidized after biodegradation. This liquid contains mercury, cadmium, lead, arsenic, chromium, and other metallic elements as well as benzene, phenol and other harmful organic matters. Wherein, the total number of the various infectious bacteria is several times to thousand times more than the ordinary water source. BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) values are up to 104 orders of magnitude. The permeate flows from the small ditch to the large ditch, flows from the stream to the river, or flows from the surface to the formations, which seriously pollutes the surface and groundwater sources, especially which are near the dumps. The higher BOD value indicates that there are more organic pollutants in the water, also means a more serious pollution. The general BOD definition refers to the total amount of oxygen consumed, when the microorganisms (e.g., the most common one is aerobic bacteria) are used to decompose the aerobic waste in the sewage. Similarly, the higher COD value indicates that the organic pollution of water is more serious. The general definition of COD refers to the total amount of oxygen, when the chemical methods are used to oxidize the all organic waste in the sewage. The difference from COD to BOD is that since some oxygen-consuming waste cannot be decomposed by bacteria, it is necessary to add other chemical, for example, strong oxidant $K_2Cr_2O_7$, in which specific chemical method is applied to oxidize the all oxygen-consuming waste in the sewage. In this case, the amount of oxygen consumed is called the chemical oxygen demand.

(2) Pollution of farmland and soil: if without treatment, only through screening, then discharged on the farmland, the garbage will cause the destruction and denaturation of soil structure, for example, desertification and alkalization; in addition, all the harmful substances—such as a large number of heavy metallic elements, phenol and other organic matter, coupled with parasite eggs, etc., through accumulating on the crops, vegetables, and herbivorous livestock—return to the human body and harm the health.

(3) Pollution of the atmosphere: the uncovered, piled-up, or simply land filled garbage, under the influences of temperature and moisture, is decomposed into some organic matters, resulting in the generation of harmful gases; in the same time, some corrupt garbage scatters the stinking smell as of rotten fish; besides making air pollution, in some more serious cases, the harmful pollutants affect the physical and mental health of the surrounding residents; in addition, there are some garbage, under the actions of natural conditions, will produce a small number of polycyclic aromatic hydrocarbons that belong to carcinogenic substances; moreover, the particles and pathogens in the garbage will be drifted with the wind and spread to the very far distance away.

(4) To become the breeding sources of mosquitoes, mice, and pathogens: the uncovered, piled-up, or simply landfilled garbage provides a good breeding environment for the mosquitoes, rats, pathogens etc., potentially possessing of the risk of the outbreak of epidemic; for example, the avian flu in the mainland China, the prevalence of several plagues in the UK, the pestilence in Mumbai, India, and the dengue fever in Taiwan, which are all relative to the breeding source of pathogens resulted from the careless management of wastes.

(5) Constraints on the social and economic development: at present, many cities are worrying about finding new waste dumps or landfills; a long time ago, since the municipal waste was stacked without reduction or classification, it had to requisition a lot of lands; however, the cost of land acquisition is more and more expensive right now, and it also involves a series of problems, such as demolition, resettlement, and compensation; as the capacity of the garbage dump in the city outskirts has been saturated, it has to seek farther

places or open up new stacking fields, which is bound to increase the costs of cleaning and transportation. Moreover, Taiwan is a small and dense island, where the land is very costly. The increasing waste disposal becomes a heavy burden on municipalities.

Overviewing the solid waste treatment methods, the reduction of volume and quantity and the resources recirculation, no harm and the commercialization are the major goals for the garbage disposal. There are four kinds of popular methods for the treatment of the general garbage, including: landfill, composing, incineration, and pyrolysis. In essence, both the incineration and pyrolysis are classified as one class. A comparison of these approaches is given in Table 6.

**Table 6 Comparison of several waste disposal methods**

| Item | Landfill | Composting | Incineration/pyrolysis |
|---|---|---|---|
| **Initial investment** | Low costs for the general filling pit, reclamation, orogeny; higher cost for sanitary landfill. | Lower cost for the general composting; higher cost for advanced high temperature and fast composting methods. | Higher |
| **Operation cost** | Lower | Lower | Higher |
| **Technical process** | Simple | Simple | Complicated |
| **Dealing adaptability** | Processing capacity is large, not affected by the waste composition changes, but the appropriate site selection is difficult, covers a large area, and the life of landfill site is short. Low degrees of garbage's volume reduction, amount reduction, harmlessness, and resource utilization. | Suitable for disposing garbage containing perishable organic matter, for example, urban garbage, sludge, sewage sludge, manure digestion sludge, livestock and poultry excrements that are generated from paper mills, food plants *etc.* and need waste water treatment. The method is also suitable for other wastes, like bark, sawdust, straw and so on. But the occupied area is also large, and the degrees of garbage's volume reduction, amount reduction, and harmlessness are low as well. But it can be partially resource utilized. | Suitable for the disposal of garbage containing more combustibles (food waste and packaging, paper, cloth, plastic, *etc.*). With the high degree of garbage's volume reduction, amount reduction, harmlessness, it can be a good resource utilization, that is, from garbage to obtain energy. |
| **Secondary pollution** | The secondary pollution of landfill leachate is serious and difficult to control. | Compost quality is difficult to control, whilst harmful ingredients often exceed the discharge standards. | If the flue gas is improperly treated, the secondary pollution will be very serious, whilst it can be controlled by advanced incineration or purification technology. |
| **Status and prospects of the various disposal approaches** | It is dominant in most of the world, but there is a downward trend for the year being, whilst it is the only and final way to process any kind of solid waste. | The installed proportions in most of the countries in the world are still small, whilst the development is slow. | In the developed countries and emerging industrial countries, the installed proportion is high, whilst it is lower in the third world countries, but the development is very rapid. |

With the continuous development of human socio-economy, the upgrading of science and technology as well as the change of industrial structure, the composition of the resulting solid waste also varies, so it is necessary to choose one or several combinations of methods according to the specific composition of solid waste. For example, the garbage of the developed countries is mostly composed of the materials of high calorific value, such as plastic, paper, and others, so the implementation of incineration power generation technology is more appropriate. On the other hand, in the developing countries, the domestic garbage composition is more complex,

in which a lot of materials can be recycled, thus that choosing a combination of several methods is more appropriate.

**Progress in solid waste incineration:** Incineration technology has the advantages of reducing volume and quantity, high processing speed, high-temperature pathogens elimination, heat recovery, and power generation. Incineration is the main means of energy utilization of solid waste, so it gains many applications. On a global scale, the technology of solid waste incineration has been in existence for more than 100 years. In 1874, Britain set up the first municipal waste incineration plant. After the Second World War, the small and medium-sized incinerators were set up in the cities of many developed countries. Especially, in 1973, the first oil crisis accelerated the fast development of solid waste-to-energy recovery technology and boomed the rapid increase of the number of incineration power plants. At present, France has 300 incineration power generation systems capable of handling 40% of municipal wastes. In Germany, the waste incineration ratio is 25%with a total garbage power generation installed capacity of 1,000MW. In Japan, the waste incineration technology has been popularized in small and medium-sized cities, which has an incineration ratio of 75% and a total garbage power generation installed capacity of 450MW.In the vast territory of the United States, the waste incineration ratio is 18%, wherein the total garbage power generation installed capacity is 2,300MW. In Netherlands, Sweden, and Switzerland, the waste incineration power generation ratios are 23%, 55%, and 70% respectively. In the Asia-Pacific region, such as Hong Kong, Macao, South Korea, Singapore, Taiwan, there are also waste incineration systems set up for the supply of heat and electricity. In 1986, Singapore constructed the first waste incineration power plant with the installed capacity capable of handling garbage of 2,760tonne/day, thus achieving a fully (100%) waste recirculation. Hong Kong has three waste incineration plants. In 1992, Macao set up two waste incineration plants to handle the garbage capacity of 576tonne/day, thus achieving a full level of waste disposal in Macao region. Basically, garbage is a low-grade fuel, when incinerated, two problems needed to be solved: (1) in the absence of oil or fewer oil condition, whether there is still a stable and complete combustion; and (2) whether it is able to effectively control the generation of dioxin, furan, and other pollutants. The furnaces suitable for solid waste incineration have been developed and they are Martin furnace, two-stage furnace, two-chamber furnace, rotary kiln, fluidized bed, refuse derived fuel, controlled air oxidation, direct-current arc smelter, thermal plasma arc verification, high/low-temperature decomposition cracking, etc. Wherein, the first application is Martin furnace. The performances of several different incinerators are shown in Table 7.

**Table 7 Performance comparison of four types of incinerator**

| Comparison item | Mechanical grate type | Modular type | Rotary type | Fluidized bed type |
|---|---|---|---|---|
| **Main application region** | Europe, US, Japan | US, Japan | US, Denmark | Japan |
| **Handling capacity** | Large capacity (over 200 tonnes/day) | Small & medium size (under 200tonnes/day) | Large & medium size (over 200tonnes/day) | Small & medium size (under 150tonnes/day) |
| **Design, manufacture, operation, maintenance** | Matured | Matured | Limited supplier | Limited supplier |
| **Pre-processing equipment** | Besides large pieces of garbage, the rest is not classified and broken. | Cannot handle large pieces of garbage | Besides large pieces of garbage, the rest is not classified and broken. | Needed to be broken with a size smaller than 5cm. |
| **Garbage disposal capability** | Good | Poor mixing effect between garbage and air | Good | Good |
| **Merit** | Suitable for large capacity, easy to deal with pollution, reliable combustion, easy operation and management, high waste heat | Suitable for small capacity, simple structure, mobile device, high mobility | Good garbage mixing and drying abilities, suitable for medium & large capacity, high-temperature safe | Suitable for medium capacity, low combustion temperature, good thermal conductibility, low pollution, low |

| | | | | |
|---|---|---|---|---|
| | utilization rate | | combustion capability, small residual ash particles | combustion efficiency |
| **Shortcoming** | High construction, operation, and maintenance costs, the continuous operation need, high tech. needed for operation | Incomplete combustion, low combustion efficiency, short life of use, high average construction cost | Complex transmission, furnace refractory damaged easily | High operational tech., limited fuel type, additional fluid media, smaller fed particles, high power per handling unit, furnace vulnerable to erosion. |

## V. THE DEVELOPMENT OF WASTE-TO-ENERGY IN THE MAJOR COUNTRIES AROUND THE WORLD

Waste-to-Energy (WtE) is primarily a waste-handling process that generates energy in the form of electricity and/or heat. In practice, WtE is a type of energy recovery technology. In terms of the inorganic matters, most of the WtE method is to burn waste to directly generate electricity and/or heat, while for the organic matters, the fermentation and other biochemical procedures are applied to produce combustible fuel products, such as methane, methanol, ethanol or synthetic fuels (Bosmans et al., 2013; Fruergaard and Astrup, 2011). Between 2001 and 2007, the WtE's waste disposal increase rate was approximately 4 million tonnes per year globally. Japan and China each built several equipment based on the technologies of direct smelting or solid waste fluidized bed combustion. In early 2016, there were about 434 WtE factories in China. Japan is the largest MSW thermal treatment user in the world with the handling capacity up to 40 million tonnes per year. Some of the latest plants utilize the coal machine technology, while the others apply the advanced oxygen enrichment technology. There are more than 100 thermal treatment plants using relatively high-tech processes, such as direct smelting, Ebara fluidization, Thermo-Select-JFE gasification, melting processes etc. In Patra, Greece, a Greek company has just completed a system test with a considerable potential, which can generate electricity of 25kW and produce heat of 25 kW from wastewater. India recently developed a first bioenergy science centre with the expectation to reduce GHG emissions and dependency on fossil fuels (Hazra and Goel, 2009). As of June 2014, Indonesia had installed the total installed capacity of 93.5MW in terms of WtE; while the total planned capacity in the future is 373MW.

**China:** Biomass energy includes energies from natural resources and waste resources. In December 2012, two specific targets have been announced by the Chinese Energy Bureau in the "Twelfth Five-year Plan for Biomass Energy Development", namely: (1) to notably encourage the development of biogas energy for the power generation through the utilization of waste in both the metropolis and the large-scale farms, and (2) on the base of local conditions to utilize the crop stalks and forestry residues to develop the biomass power generation, gasification technology, and solid-formed fuels. In present China, the waste-to-energy reserved in the straw and agricultural products is equivalent to 430 million tonnes of standard coal/year, but the achieved utilization ratios only 11.6%.In the meantime, the biomass energy power generation installed capacity is 13 million kilowatts with an annual generated electricity of about 78TWh, in which the yield of biomass liquid fuel is 5 million tonnes per year, the production amount of biomass-formed fuel is 10 million tonnes per year, and the produced volume of biomass gas is 22 billion cubic meters per year (Zhuang Z.-R., 2015; Chyang and Wan, 2008). According to the REN21-2016 Report, in 2015, the biomass power generation in China is 48TWh ranked third in the world, less than 69TWh of the United States, and 50TWh of Germany. In terms of biomass gas, Chinese rural small biogas utilization has been developed for many years. In the recent years, the industrial biogas is also developed. Compared with other countries, the resources of biomass gas in China is very abundant and the commercialization development is fast maturing. According to the statistics of the International Energy Agency (IEA), in 2011, Chinese biogas utilization accounted for 31% of the world, second only to the European Union. In 2014, the biogas installations in China are 43 million, ranking first in the world. The Sino-German biogas project—the first living garbage fermentation biogas station in China and co-invested by the Chinese Ministry of Agriculture and the German government—started to operate in 2014, capable of handling 160 tonnes of daily

garbage, after one month of fermentation, producing 8,000 cubic meters of biomass gas, available for the fuel use of 600 cars. Basically, Chinese biogas technology has already been in the stages of commercialization and large-scale application, possessing of very strong market competitiveness. Currently, there are a lot of governmental subsidies for the waste energies including the solid waste derived fuels, particularly, for the development of agricultural and forestry waste energies. However, the raw material acquisition is the biggest problem in China. Due to the small specific weight, the large volume, the low calorific value, the complex category, and the wide scattering range, the collection and transportation of the existing crop straws and forestry residues are difficult. In the lack of raw materials, the current companies almost all face a loss situation. The raw materials acquisition costs are intensified, resulting in the fuel prices continuing to grow. In addition, limited by the crop harvest season, the storage of straw after the harvest also requires additional costs. In the wide variety of agricultural and forestry wastes, it is not possible to convert different materials at the same time. To control the dust flying during processes, more sophisticated equipment is needed, resulting in the increase of investment cost. At present, Chinese government provides a subsidy policy on the production equipment to develop biomass biogas industry. Therefore, the industry is so opportunistic that they only focus on the equipment investment and neglect the enterprise's operation, management, and innovation. Subsidy policy must be changed from the equipment subsidy to the production subsidy, in order to put an end to this malpractice.

**Japan:** With the global energy price volatility and the increasing climate change intensity, the implementation of energy saving and carbon reduction is becoming an important energy policy/measure around the world. After the earthquake, tsunami and Fukushima nuclear disaster occurred on March 11, 2011, Japan has been paying more attention to the application and industrialization of non-nuclear waste-to-energy. In contrast, the waste-to-energy application in Taiwan still limits on incineration-based implementation, of which the energy efficiency is very low. Japanese efficient waste disposal is worthy of emulation by Taiwanese energy policy makers. Japan is the most energy-efficient country in the world. Japanese government is committed to the improvement of energy efficiency, which not only can reduce the dependence on imported energy and GHG emissions, but also can mitigate the impact of reduced nuclear power supply brought about by the Fukushima incident. The development of waste-to-energy is not only a concrete characterization of energy efficiency but also a sustainable strategy (Kothari et al., 2010). Since the weather in Japan is very cold in winter and very hot in summer, not only the cogeneration system simultaneously generating steam and electricity are widely implemented in the industrial sector, but also the heating and cooling systems driven by waste heat are popularized in the household sector. Wherein, the phenomena of waste derived fuels used in these systems are quite common. Recently, the Japanese government has proposed a national plan for the recirculation of wastes. Wherein, the corresponding development targets for 2020 were also announced. In addition to the livestock and poultry excreta, the utilization ratios of food waste, waste paper, sewer sludge, wood waste and unused materials as well as the straw and rice husk of non-edible parts of crops are also increased. Japanese heating energy sources are still dominated by natural gas, but due to the international oil price fluctuations, the fuel costs are difficult to control, which promote the Japanese government committed to use waste-to-energy in the district heating system. According to the forecast by the IEA (2013), the electricity generated by waste-to-energy will reach 5,500GWh in Japan by 2020. In order to reward the utilization of waste-to-energy, the Japanese government specifically proposed the relevant targets for 2020, as shown in Table 8 and described in the following.

**Table 8 Japan's different waste-to-energy goals to be achieved before 2020**

| Waste category | Annual production (ten thousand tonnes) | Utilization ratio (2009→2020) |
|---|---|---|
| **Poultry manure** | 8,800 | 90→90 |
| **Sewer sludge** | 7,800 | 77→85 |
| **Black liquor** | 1,400 | 100→100 |
| **Waste paper** | 2,700 | 80→85 |
| **Food waste** | 1,900 | 27→40 |
| **Wood corners of production and construction (sawmill)** | 340 | 95→95 |
| **Wood corners of construction** | 410 | 90→95 |
| **Un-edible crops** | 1,400 | 85→90 |
| **Wood biomass (forest corners)** | 800 | 0→30 |
| **Total** | 25,550 | |

Notes: black liquor, wood for production and construction, wood waste, etc. for the dry weight, other categories with water content. Data sources: Japan Agriculture, Forestry and Fisheries Ministry (2013), The Guidebook for Promoting Biomass Town Concept.

(A) In an investigation of livestock and poultry excrement, Japan produces about 89 million tonnes of livestock and poultry excrement each year, of which 90% is treated as organic water and fertilizer. It is noteworthy that in the southern region of Japanese Kyushu, an animal husbandry-intensive area, due to the factors of malodour, nitrogen fertilizer transport, and others, most of the livestock and poultry excrement are directly transported to the local farmland to process the organic fertilizer reduction, so there is a phenomenon of over fertilization. Basically, their utilization ratio remained at an unchanged 90% from 2009 to 2020.

(B) Food waste In 2001, Japan produced about 22 million tonnes of food waste. The Japanese law regulated that the conversion ratio of food waste to fertilizer or feed was 10% but it will be doubled to 20%. In other words, 80% of the food waste is not effectively utilized. At present, the main way to treat food waste is still limited on burning or burial. The impact on the environment is very large and most of all, it does not meet the principle of efficiency. As a result, after 2009, its utilization ratio is expected to gradually increase and double to 40% by 2020.

(C) Waste paper Japan produces about 36 million tonnes of waste paper per year, of which about half are treated as recycled paper and 16 million tonnes are burned, with 70% of the heat generated being used for other purposes. In addition, the black liquor produced by the paper industry is about 14 million tonnes per year. Most of them are dried first and then burned to obtain the heat generated. In 2009, Japanese waste paper production fell to 27 million tonnes, but in 2020 the recycling ratio will increase from 80% to 85%.

(D) Sewer sludge Japanese sewer sludge production (i.e., the concentrated sludge) is about 75 million tonnes, of which 36% are buried and the remaining 64% are used as building materials or organic fertilizers. In addition, the amount of waste sludge produced in rural settlements is about 29 million tonnes per year, and the majority of the rest are treated by incineration, except for a small portion to be used as organic fertilizers. The utilization ratio of sewer sludge will increase from 77% in 2009 to 85% in 2020.

(E) Wood waste Wood waste can be divided into three types: first, the left waste wood/chip after the wood materials are produced in factories, of which the annual output is about 5 million tonnes, and most of them are used as fuel or organic fertilizer; the second is the waste wood from the cut-off planted trees, of which the amount is about 3.7 million tonnes per year, and which has not been used yet; the last is the building materials waste, of which the amount is about 4.6 million tonnes per year and their reutilization ways are mainly as pulp and for the direct burning. The recirculation ratio of wood waste will increase from 90% in 2009 to 95% in 2020.

(F)Straw, rice hull, and other non-edible crops The output of straw, rice hull, and other non-edible crops in 2009's Japan was about 14 million tonnes, of which 30% was used as organic fertilizer and feed, and the remaining 70% (mainly rice husk) was not properly utilized. In addition, the Okinawa area is rich in sugar cane bagasse that has not been reused yet. In the future, the sugar cane bagasse is expected to be refined as raw materials, such as ethanol and other raw materials. The utilization ratio will be boosted from the current 85% to 90% in 2020. At present, in Taiwan, the MSW treatment is still limited to incineration. With reference to Japanese thermal energy utilization norms, Taiwan should switch to the high-efficient gasification for improving the thermal energy utilization and further expanding the mechanisms of heat supply, power generation, or cooling. Japanese high waste utilization ratio is worth learning by Taiwan.

## VI. CONCLUSION, DISCUSSION, AND PROSPECT

Waste in accordance with the physical type can be divided into three categories: liquid, solid, gaseous. This classification has a great relationship with the subsequent processing procedures or the use of technology. If in accordance with the source used, there are three types of waste: the agricultural, forestry, and animal husbandry wastes; the industrial waste; and the domestic waste. These three

wastes come from three different users, so there are many differences in physical and chemical properties. Generally, the common disposal manners of waste are first sorted in each department and then collected for the individual processing. Wherein, the energy potential of waste resource in Taiwan is about 12,260.92GWh/year with an estimated installed capacity of 4,220MW, which are3.78 times of the current waste power generation (3,243.7GWh/year) and 6.71 times of the existing waste power installed capacity (629.1MW). It can be seen that the waste-to-energy potential in Taiwan isso compelling. At present, 1,369MW of the waste power generation installed capacity is set by the Governments the development target by 2030, which is very conservative, compared with above estimated potential. The main reasons for this difference are that Taiwanese agricultural and forestry waste shave not been utilized yet, the kitchen waste recycling ratio is too low, and especially, the livestock and poultry excrement is not widely used. In the waste thermal disposal technology, the incineration technology currently used in Taiwan is slightly outdated, due to the low efficiency and high pollution. Government should consider the development of gasification and cracking technology coupled with use of waste derivative fuels that can provide the merits of high calorific value, low pollution, easy transportation, and multiple industrial applications. For the biogas power generation from animal excrement, the corrosion problem is the major shortcomings that should be overcome first.

The appropriate introduction of foreign advanced technology and equipment has a chance to sufficiently develop the total biogas power generation potential of 1,700TWh reserved in the livestock and poultry excrement. This data is calculated on the case study of the Kaohsiung's Shih-An Farm and the information from BOEMOEA (2015). Taiwanese recycling ratio of waste resources has increased year by year, further reaching 45.92% in 2015. A large amount of industrial raw material resources has been recycled from the domestic wastes, such as aluminium foil bags, aluminium cans, tin cans, and paper. All these wastes recirculated as industrial raw materials can save a large amount of energy required for smelting, reducing, and pulping processes. The estimated benefits are the energy saving as high as 146.79 million kloe and the mitigation of carbon dioxide emissions is 3.20 million tonnes, which are equivalent to the oil imports of about 922.56 million barrels and the planting of 8,236 Da'an Forest Parks. Compared with the oil import of 307.09 million barrels and the CO2 emissions of 252.7 million tonnes in 2015's Taiwan, the utilization of waste-to-energy can address the energy security, the environmental protection, and other national issues in the country. Taiwan has three nuclear power plants operated by six units with a total power generating capacity of 5,144MW. The estimated used fuels are about 150 tonnes (about 57 cubic meters) per year and there are about 15,000 barrels (one barrel equals 55 gallon) of low-and-medium grade nuclear waste produced. If further considering the factor of decommission, in the operating period of about 30 years of a nuclear plant, the total high-strength nuclear waste will be about 9,000 tonnes and the low/medium strength nuclear waste will be up to 900,000 barrels.

Taiwanese current nuclear waste disposal policy not only constitutes a strong threat of unexploded bombs, but also deeply damages the environment and human health. More seriously, it maybe extends the woe to the next generations for thousands of years. In theory, 97% of the nuclear waste can be reused. In accordance with the concept of circular economy, the volume and amount of waste should be reduced significantly, in order to make good use of waste-to-energy, the Government policy should be changed, so that the nuclear waste can be reprocessed into a useful secondary energy (Lu, 2017). In 2015's Taiwan, the waste production per capita is 0.844 kg/day, with a decreasing rate of 10.17%, if compared with ten years ago. However, the amount of resource recovery increases 83.44%, while the industrial waste recycling ratio is 82.51%. Taiwanese waste recycling efficiency and progress are so amazing that it becomes an example of success in the world. The hazards of unhandled, piling-up or uncovered garbage can be roughly summarized as follows: pollution of water, pollution of farmland and soil, pollution of the atmosphere, becoming the breeding sources of mosquitoes, mice, and pathogens as well as forming the constraints of social and economic development. Reducing the waste's volume and quantity, resource recirculation, no harm, and commercialization are the pursuit goals of garbage disposal. The current treatment methods of garbage in the world can be summarized

into four categories: landfill, composing, incineration, and pyrolysis. With the continuous development of human socio-economy, the progresses of science and technology as well as the variety of industrial structure, the composition of the resulting solid waste also changes. Therefore, according to the specific composition of solid waste, one or several combinations of methods are applied. For materials of high calorific value, such as plastic, paper, and others; the suitable disposal method is the technology of incineration power generation. If the garbage composition is more complex with many recyclable substances, a combination of several methods is more appropriate. Basically, the garbage is a low-grade fuel. Currently, in the incinerating process, there are two problems to be solved: (1) in the absence of oil or fewer oil conditions, whether a stable and complete combustion can be maintained; (2) whether an effective control of dioxin, furan, and other pollutants generated can be achieved. In China, due to the vast territory and abundant population, the waste yields of living, agriculture, forestry, animal husbandry, industry and others are so amazing that the development of waste energies are prioritized as the major national energy policy (Liu, 2010). According to the REN21 Annual Statistical Report for 2016, the Chinese renewable energy power generation (including hydropower and not including hydropower) ranks first in the world. Especially, in China, the number of biogas power station is up to 43 million that is far more than the second-ranked India of 4.75 million. Basically, Chinese waste biogas technology has been in a commercial and large-scale application stage, possessing of the very strong market competitiveness. However, Chinese agricultural and forestry waste-to-energy is much less developed, because the raw material acquisition is the biggest problem. Currently, there are many companies already facing the loss situation.

In terms of energy efficiency, there is no doubt that Japan ranks number one in the world. After Fukushima nuclear disaster, with the tighter nuclear energy supply, the waste energies have been urgently applied in Japan, almost including the all organic and inorganic waste energies, of which 88.84% of the outputs per year are: 89 million tonnes of livestock and poultry excrement, followed by 78 million tonnes of sewer sludge, 27 million tonnes of waste paper, 19 million tonnes of food waste, and 14 million tonnes of non-edible portion of the crop. Except forthe food waste, the remaining waste utilization ratios are as high as 80-90%. Taiwanese kitchen waste, accounted for 40.9% of the total waste produced, has a recycling ratio of only 8.43%.Compared with Japan, it is clear that the global food waste recycling ratio or related technologies should be improved. In Taiwan, the amount of livestock and poultry excrements is also very high, about 27.2 million tonnes per year, almost 63 times the human excreta of 430,518 tonnes. In Taiwan, the livestock and poultry excrement has the potential to produce about 1.834 billion cubic meters of biogas. Based on the data of a Danish CSRT livestock biogas power generation system operated in the Kaohsiung's Shih-An Farm, Taiwanese animal waste biogas power generation potential is as high as 1,700TWh per year, about 6.59 times the current annual total generating capacity of 258TWh. Meanwhile, the biogas utilization or power generation implementation in China can be emulated by Taiwan as a concrete solution for effectively addressing the both energy and environmental issues (Pavlas et al., 2010).

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## Energy unit conversion table:

1 kloe = 6.29 barrels of crude oil

1 calorie = 4.2 Joule

1 kWh = 0.248 kloe

1 GJ = 277.78 kWh

1 EJ = 103 PJ = 109 GJ = 1015 kJ = 1018 J

1 kloe= 1000 loe= 37.681 GJ

1 kWh= 3600 kJ=2,236 kcal

1 GWh = 3600 GJ = 95.539kloe = 0.095539mloe

1mloe = 1,000 kloe = 10.47 GWh

10 mloe = 0.1047TWh～0.1TWh

1 kloe = 10,470 kWh

1 litre fuel oil＝9,200kcal

1 kg steam coal＝6,400 kcal

1 TOE=41.868 GJ = 10 Gcal，

Electricity emission coefficient (2010 Taiwan)=0.612 kg-$CO_2$/kWh = 612 tonne-$CO_2$/GWh

Thermoelectric conversion factor =0.420 trees of 20-40 years can produce 1 tonne of pulp

The absorption of $CO_2$ in the 1 year of Da'an Forest Park is 389 tonnes

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## Appendix

The energy use and GHG emissions of the six largest industries in Taiwan—petrochemical, electrical machinery, iron and steel, textiles, cement, paper and pulp (2010) (Lu et al., 2013).

| Index | Energy use (BOEMOEA, 2010) | Industrial sector share | Yield[a] | Output value (MOEA, 2010) | Specific product energy use[b] | Energy intensity[c] | Specific product GHG emissions[d] | Emissions intensity[e] | Main product | Main energy use process |
|---|---|---|---|---|---|---|---|---|---|---|
| Industry/Unit | $10^3$ kloe | % | Mt | 100 million NT$ | loe/kg | loe/$10^3$ NT$ | kg-$CO_{2e}$/kg | kg-$CO_{2e}$/$10^3$ NT$ | | |
| Petrochemical | 33,450.9 | 51.67 | 4.2 | 20,700 | 0.65 | 16.16 | 5.20 | 41.74 | Ethylene | Distillation |
| Electric machinery | 9,184.0 | 14.19 | - | 78,000 | - | 1.18 | - | 1.35 | Semi-con ductor | Clean room HVAC |
| Iron and steel | 6,046.4 | 9.34 | 15.81 | 14,187 | 0.38 | 4.26 | 0.75 | 8.32 | Crude steel | Iron oxide reduction in blast furnace |
| Textiles | 2,204.7 | 3.41 | 3.88 | 4,820 | 0.57 | 4.57 | 0.96 | 7.68 | Chemical fiber | Fiber-making, Spinning, Dyeing and Finishing |
| Cement | 1,828.4 | 2.82 | 16.88 | 362 | 0.11 | **50.51** | 0.31 | **143.65** | Cement | Clinker calcinations, Grinding |
| Paper and pulp | 1,329.7 | 2.05 | 4.45 | 1,679 | 0.30 | 7.92 | 0.56 | 14.89 | Paper | Pulping, Papermaking |
| Total or average | 54,043.6 | 83.48 | - | 119,748 | - | 4.5 | - | 10.03 | - | - |

Notes: [a] Steel News Letter, Customs Import and Export Statistics, Metal Center, and Taiwanese Paper Industry Association.
[b] Specific product energy use=Energy use ÷ Yield. [c] Energy intensity=Energy use ÷ Output value. [d] Specific product GHG emissions=GHG emissions ÷ Yield. [e] Emissions intensity=GHG emissions ÷ Output value.

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